AD A

# INVESTIGATION OF AFB GROUND VAPOR EXTRACTION & COMBUSTION USING A DIESEL ENGINE

**INTERIM REPORT**
**No. TFLRF 383**


by

**Matthew E. Schulman**

**U.S. Army TARDEC Fuels and Lubricants Research Facility**
**(SwRI®) Southwest Research Institute®**
**San Antonio, TX**



Under Contract to

**U.S. Army TARDEC**
**Petroleum and Water Business Area**
**Warren, MI**

Contract No. DAAE-07-99-C-L053 (WD 07)


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**April 2006**

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**Approved by:**

**Edwin C. Owens, Director**
**U.S. Army TARDEC Fuels and Lubricants**
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13. ABSTRACT (Maximum 200 words)

This project aims to remediate fuel spills by extracting hydrocarbon vapors from contaminated earth, and burning them in a diesel engine. The diesel engine destroys hydrocarbons more effectively than spark-ignited units currently in use, uses less fuel, uses fuel commonly available on Air Force installations, and produces usable electrical power as a by-product. A surplus diesel-powered electrical generator was fitted with measurement and control mechanisms for the project. Limitations were identified in terms of the concentration of gaseous fuel, hydrocarbon destruction efficiency and the fuel required. The unit's operation was tested during six days of operation connected to extraction wells at Kirtland AFB, in Albuquerque, New Mexico.

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## EXECUTIVE SUMMARY

**Problems and Objectives:** Environmental and health hazards posed by soil contamination resulting from underground fuel tank leakage and spillage at U.S. Air Force bases has created a need for cost-effective methods of removing volatile and combustible compounds from subterranean soil. Following removal of as much liquid-state contaminant as possible from a site, the next step in the clean-up process is further removal of contaminant in gaseous form as it evaporates from the saturated soil. One method employed is to bore a well, insert a pipe into the contaminated soil and route the vapors into the intake of a running engine for combustion.

Current engines used for this task are spark-ignited automotive models using propane or natural gas as supplemental fuel during startup and lean vapor conditions. The purpose of this project is to investigate whether a compression-ignition (CI) diesel engine could perform the same function, perhaps increasing efficiency, durability and reliability.

**Importance of Project:** Continuous operation of an engine for this purpose can result in significant maintenance cost over time. The inherently sturdier design of compression-ignition engines predicts greater durability and a longer life cycle between rebuilds. Other important advantages that a CI engine may offer in this application are the capability to operate at leaner air-fuel ratios and the ability to use readily available JP-8 as a supplemental fuel instead of bottled gases. Using a liquid fuel could also reduce the requirement for refueling, since a larger tank could be used, thereby reducing the associated labor costs.

**Technical Approach:** A diesel-electric generator set obtained from Air Force surplus inventory was equipped for operation as a pre-mixed vapor dual-fuel test platform. The engine was operated at various steady state speed and load conditions while the gas to air ratio in the intake air stream was incrementally increased. At each test point, the cylinder pressure was monitored for indications of potentially damaging knock, and parameters such as fuel and air consumption rates and engine temperatures were recorded.

**Accomplishments:** The device was devised, constructed, refined and tested in preparation for a field test at a typical well site. Data was acquired at a wide range of engine speed, load and intake pressure conditions, using different concentrations of the well gases, to investigate and describe how the engine will operate in actual use.

**Military Impact:** The results of this limited study show promise for the possibility of using diesel engines in the task of removing and destroying fuel vapors from underground contamination sites. If the concept ultimately proves practicable through further investigation, it could potentially increase the effectiveness and reliability of engine-based ground vapor removal systems while simultaneously reducing the maintenance costs associated with them.

## FOREWARD / ACKNOWLEDGMENTS

The U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, performed this work during the period July 2003 through April 2006 under Contract No. DAAE-07-99-C-L053. The U.S. Army Tank-Automotive RD&E Center, Petroleum and Water Business Area, Warren, Michigan administered the project. Mr. Luis Villahermosa (AMSTA-RBFF) served as the TARDEC contracting officer's technical representative. Mr. Jerry Hansen, U.S. Air Force Center for Environmental Excellence, provided technical advice and program direction.

Special acknowledgement is given to the entire staff of U.S. Army TARDEC Fuels and Lubricants Facility (SwRI) for dedication and support in conducting this program. Special thanks to Linda De Salme for editorial processing.

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# 1.0 BACKGROUND AND OBJECTIVE

This project aims to remediate fuel spills by extracting hydrocarbon vapors from contaminated earth, and burning them in a diesel engine. The diesel engine destroys hydrocarbons more effectively than spark-ignited units currently in use, uses less fuel, uses fuel commonly available on Air Force installations, and produces usable electrical power as a by-product. A surplus diesel-powered electrical generator was fitted with measurement and control mechanisms for the project. Limitations were identified in terms of the concentration of gaseous fuel, hydrocarbon destruction efficiency and the fuel required. The unit's operation was tested during six days of operation connected to extraction wells at Kirtland AFB, in Albuquerque, New Mexico.

# 2.0 ACCOMPLISHMENTS

A 60-kW genset for project use was delivered to SwRI on 13 November 2003. The unit was installed in a test cell, with devices to provide and measure fuel flow, monitor the genset's instruments, and to apply and dissipate electrical load.

An appropriate controller for the GVEC system was selected based on its capabilities, price and availability and was acquired along with the software required for the project work. To monitor genset operation for control purposes, instrumentation was added to electronically monitor:

- the genset controller's command signal to the fuel pump actuator
- the electrical power output
- intake pressure upstream and downstream of the turbocharger
- exhaust oxygen content

To implement the control functions, two electronically controlled and monitored throttle valves were installed upstream of the air filter — one to control flow from a well, and the other to control bypass airflow. Their combined operation controls the total flow into the engine, therefore also the pressure upstream of the turbocharger, and the relative mixture of well gases and bypass air.

An air enclosure was fabricated from a surplus ammunition can, to house the two throttle valves, an air filter, the intake manifold pressure valve, and a drain valve. See Figure 1 below. The two throttle valves are arranged to breathe through flanges on the outside of the can. One will induct fresh bypass air; the other will control flow from a well. An air filter is mounted inside the can, so that flow from both sources will be filtered before entering the engine. A pressure sensor capable of measuring 40-120 kPaa is mounted inside the can, to monitor the vacuum applied to the well. On the bottom of the enclosure is a drain valve, to empty water buildup from the can during maintenance.

The 180° elbow in the exhaust pipe connected to the turbocharger outlet was modified to mount an exhaust oxygen sensor. See Figure 2 below. The ether system injection jet was relocated to a T-fitting, so that another pressure sensor can be added to that site. This sensor, capable of sensing 90-450 kPaa, will monitor the engine's manifold pressure.

**Figure 1. (left) Flow Control Enclosure Installed on Front of Genset**

**Figure 2. (below) Oxygen Sensor Installed in Exhaust Elbow**

A range of problems occurred during the work. The most important, both technically, and in terms of time and cost to correct, were genset controller failures. The cause of these failures appears to be accidental grounding of the fuel pump actuator drive circuit, through the circuits added to monitor the genset operation. The grounding events resulted in failed components on the genset controller circuit board. In the first instance, there was no visible damage on the board. Attempts at diagnosis and correction consumed several months and a substantial share of the project budget. A second failure, likely similar in cause to the first, occurred when the same circuit grounded along a second grounding path, after the first one was identified and isolated.

Two new Genset controllers were ordered and arrived several months later. The new units are made by Woodward, and are labeled as a direct exchange for the DYNA-10502-003-0-24 controller they are to replace. One of the new controllers was installed on the genset, along with replacements for the ammeter and hour meter, which were not working when the genset arrived at SwRI. All GVEC instrumentation was removed from the genset in order to test the new controller's fitness for the task. The genset was started, warmed up, and a range of loads was applied. The genset did function correctly with the new replacement controller. Woodward repaired the damaged genset controller successfully, and it is now on hand as a potential replacement, for this or another generator. There is reason to believe that the same service could repair the other failed controller, if another working one were required.

Several electrical circuits were devised, constructed and installed:

- New circuits designed to eliminate the previous grounding problems were installed on the genset and tested successfully.
- A circuit was designed to better measure the fuel command signal given by the genset controller to its fuel pump actuator. Previous attempts to measure this command produced unusable results.
- A wiring harness connecting the controller to the added sensors and actuators, the genset itself, and an external load bank was constructed. It was necessary to order some electrical connectors, and to determine the best way for the controller to communicate with the various peripheral devices.
- Coordination with a representative of Technology Research Corporation of Clearwater, Florida, which produced the fault light unit on the genset, revealed a technique for the GVEC controller to sense if any of those faults are active.
- The asymmetrical discharge of the unit's two electrical storage batteries was remedied with the addition of a regulated DC-DC power supply, which draws power from the pair of batteries, loading them equally, and supplies 12 volts, up to 12.5 amps, to the GVEC system. The power supply does add some cost, complexity and packaging requirement to the overall system, but is considered to be a necessity.
- A series of problems relating to sensing and actuating the throttle valves was traced to a faulty chip in the GVEC controller. The chip was replaced at the factory, and the unit was resealed and shipped back to SwRI to continue controls work.

A program in C and Matlab was devised to implement the control techniques previously agreed upon. The software was flashed to the controller, and tested in simulation to exercise each of the functions. Once a wiring harness was available, the controller was installed on the genset, to perform calibration work to correlate sensor and actuator signals to physical parameters used by the control program. There will be some troubleshooting requirements, and some software enhancements will be developed and implemented.

As the GVEC system does not have direct control of the genset load, the project controls engineer implemented techniques to control the system without it in the initial field tests. This somewhat compromises the system's ability to optimize the vacuum applied to the wellhead, and to optimize fuel economy, but it should still perform the extraction and destruction functions, and should run without damage.

In preparation for the upcoming field test and transportation, all wiring and control system devices were remounted in a weatherproof enclosure. The electrical wiring, fuel lines, exhaust pipes, etc. that connected the GVEC system to the test cell were removed. The device was securely mounted on a trailer, on which it was transported to the field test site, stayed on the trailer during operation, and was removed only upon its return to SwRI. A rack of gas bottles was similarly bolted to the trailer, and all other ancillary test equipment, including the laptop computer being used to interface with the GVEC controller, and hydrocarbon analyzers to monitor its performance during testing, was loaded into the heavy-duty pickup truck that pulled the trailer. The complete rig in place at the test site is shown in Figure 3.

**Figure 3. GVEC System Prepared for Field Test**

The System arrived in Albuquerque on Sunday, 16 October 2005, and was in place at the test site by noon on the 17th. Setup occupied the remainder of that day. Problems with the hydrocarbon analyzers consumed all of the next day and part of the next, but by nightfall on the 19th, baseline measurements with one analyzer were underway. Those measurements were completed on the 20th; the remainder of that day was occupied with transforming the data into a usable form, and experimenting with the system's reaction to well gases. The system consumed well gases on the 21st and part of the 22nd, and generated much useful data. All equipment was again prepared for movement by the end of the 22nd, and the entire system returned to SwRI on Sunday, 23 October.

The data acquired characterized the system's performance under four levels of load and various levels of vacuum, while connected to four different wells — which is to say, four different mixtures of gases. There were nine wells available, and some data was acquired from each, but some were found to be unsuitable for this testing because of low hydrocarbon levels, or because of water in the well. A selection of the acquired data is shown below, in Table 1.

**Table 1. Selected Field Test Data**

| | | | | | Well | | | | Manifold | | | | Exhaust | | | | Fuel | Elect. | F:A | Manif. | Well | Bypass | Well |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run | Load | Well | Pressure | Notes | CO | HC | $CO_2$ | $O_2$ | CO | HC | $CO_2$ | $O_2$ | CO | HC | $CO_2$ | $O_2$ | cons | load | ratio | press. | press. | throt | throt |
| # | kW | # | bar | | %vol | ppmV | %vol | %vol | %vol | ppmV | %vol | %vol | %vol | ppmV | %vol | %vol | lb/hr | kW | - | bar | bar | % open | % open |
| 043 | 12 | 1 | max | | 0.07 | 36600 | 5.02 | 6.72 | 0.01 | 3370 | 0.46 | 20.34 | 0.37 | 650 | 4.78 | 14.02 | 7.4 | 10.5 | > 29.35 | 0.94 | 0.828 | 99.9 | 99.9 |
| 044 | 12 | 2 | max | | 0.07 | 20300 | 13.16 | 3.44 | 0.01 | 1180 | 0.94 | 20.40 | 0.14 | 265 | 5.42 | 14.08 | 10.4 | 10.5 | > 29.35 | 0.93 | 0.827 | 99.9 | 99.8 |
| 045 | 12 | 3 | max | | 0.08 | 19800 | 8.70 | 1.72 | 0.01 | 1490 | 0.80 | 19.80 | 0.16 | 332 | 5.26 | 13.46 | 9.6 | 10.4 | > 29.35 | 0.93 | 0.828 | 99.9 | 99.8 |
| 051 | 12 | 9 | max | | 0.07 | 30740 | 5.70 | 6.66 | 0.00 | 1595 | 0.30 | 20.22 | 0.16 | 357 | 4.76 | 14.06 | 9.3 | 9.2 | > 29.35 | 0.93 | 0.827 | 99.8 | 99.7 |
| 041 | 12 | - | max | | 0.00 | 455 | 0.00 | 21.56 | 0.00 | 19 | 0.04 | 22.11 | 0.03 | 19 | 4.76 | 15.60 | 11.1 | 10.8 | > 29.35 | 0.92 | 0.827 | 99.9 | 100.0 |
| 052 | 12 | 1 | 0.82 | min fuel | 0.06 | 37760 | 4.92 | 6.32 | 0.01 | 5580 | 0.68 | 19.12 | 0.63 | 1172 | 4.88 | 12.78 | 2.9 | 9.9 | 29.35 | 0.94 | 0.820 | 58.3 | 98.5 |
| 057 | 12 | 9 | 0.8 | speed oscillation | 0.08 | 28200 | 4.30 | 10.20 | 0.01 | 4320 | 0.68 | 20.06 | 0.43 | 850 | 5.30 | 13.42 | 8.7 | 11.6 | > 29.35 | 0.91 | 0.800 | 41.1 | 98.8 |
| 042 | 12 | - | 0.8 | | 0.00 | 321 | 0.02 | 20.48 | 0.00 | 20 | 0.02 | 20.84 | 0.03 | 23 | 4.84 | 14.40 | 11.4 | 11.6 | > 29.35 | 0.88 | 0.800 | 42.7 | 98.7 |
| 054 | 12 | 3 | 0.79 | engine oscillation | 0.07 | 18730 | 8.42 | 1.46 | 0.01 | 4220 | 2.10 | 16.12 | 0.42 | 919 | 6.82 | 9.44 | 6.9 | 9.9 | 23.58 | 0.92 | 0.790 | 32.6 | 98.5 |
| 053 | 12 | 2 | 0.77 | engine oscillation | 0.04 | 15800 | 10.40 | 7.10 | 0.01 | 5050 | 3.72 | 16.16 | 0.51 | 983 | 8.60 | 9.02 | 6.1 | 9.9 | 22.66 | 0.92 | 0.770 | 28.1 | 98.5 |
| 079 | 30 | 1 | max | | 0.00 | 342 | 0.04 | 21.24 | 0.00 | 15 | 0.04 | 21.68 | 0.01 | 14 | 6.96 | 12.50 | 23.7 | 25.6 | > 29.35 | 1.09 | 0.827 | 99.5 | 99.4 |
| 080 | 30 | 2 | max | | 0.07 | 21280 | 13.64 | 2.96 | 0.00 | 1270 | 0.96 | 20.52 | 0.10 | 144 | 7.62 | 11.30 | 19.9 | 25.7 | 28.04 | 1.11 | 0.828 | 99.5 | 99.4 |
| 081 | 30 | 3 | max | | 0.00 | 3830 | 2.46 | 18.02 | 0.00 | 74 | 0.10 | 21.62 | 0.02 | 37 | 6.96 | 12.42 | 23.7 | 25.4 | > 29.35 | 1.10 | 0.827 | 99.5 | 99.4 |
| 082 | 30 | 9 | max | | 0.07 | 32530 | 6.00 | 5.92 | 0.01 | 2240 | 0.42 | 20.68 | 0.17 | 231 | 7.06 | 11.54 | 17.7 | 25.4 | 28.41 | 1.10 | 0.828 | 99.5 | 99.4 |
| 058 | 30 | - | max | | 0.00 | 680 | 0.06 | 21.62 | 0.00 | 66 | 0.04 | 22.02 | 0.02 | 62 | 6.94 | 12.72 | 22.4 | 27.8 | > 29.35 | 1.12 | 0.830 | 99.3 | 99.8 |
| 078 | 30 | - | max | | 0.00 | 488 | 0.06 | 20.92 | 0.00 | 23 | 0.04 | 21.54 | 0.01 | 15 | 6.96 | 12.42 | 23.9 | 25.5 | > 29.35 | 1.09 | 0.828 | 99.5 | 99.4 |
| 084 | 30 | 1 | 0.808 | max vac – detonation | 0.06 | 37250 | 4.96 | 6.38 | 0.02 | 6890 | 0.84 | 18.82 | 0.32 | 386 | 7.32 | 9.82 | 9.3 | 27.4 | 25.08 | 1.04 | 0.808 | 43.9 | 98.2 |
| 085 | 30 | 2 | 0.8 | | 0.07 | 23440 | 12.08 | 4.54 | 0.01 | 2340 | 1.56 | 18.96 | 0.18 | 234 | 8.46 | 9.48 | 19.4 | 27.6 | 25.12 | 1.06 | 0.800 | 41.5 | 98.1 |
| 086 | 30 | 3 | 0.8 | | 0.08 | 25190 | 7.54 | 4.02 | 0.01 | 2450 | 0.80 | 19.08 | 0.18 | 243 | 7.76 | 9.78 | 19.9 | 27.4 | 25.51 | 1.05 | 0.800 | 42.0 | 98.1 |
| 087 | 30 | 9 | 0.8 | | 0.07 | 33040 | 5.28 | 6.76 | 0.01 | 5090 | 0.74 | 19.00 | 0.41 | 356 | 7.44 | 9.80 | 13.4 | 27.6 | 25.01 | 1.05 | 0.800 | 40.8 | 98.1 |
| 083 | 30 | - | 0.8 | | 0.00 | 638 | 0.08 | 21.06 | 0.00 | 29 | 0.04 | 21.62 | 0.01 | 26 | 7.30 | 11.96 | 23.7 | 27.7 | 29.35 | 1.05 | 0.800 | 44.8 | 98.0 |
| 090 | 30 | 9 | 0.79 | detonation | 0.06 | 33430 | 4.94 | 7.12 | 0.01 | 5980 | 0.82 | 18.76 | 0.41 | 387 | 7.54 | 9.38 | 10.7 | 27.6 | 23.62 | 1.05 | 0.790 | 35.8 | 97.9 |
| 089 | 30 | 3 | 0.784 | oxygen limit | 0.07 | 20020 | 8.38 | 1.54 | 0.01 | 4790 | 2.24 | 15.88 | 0.38 | 340 | 8.96 | 6.28 | 14.1 | 27.6 | 19.72 | 1.06 | 0.784 | 31.7 | 98.0 |
| 091 | 30 | - | 0.78 | | 0.00 | 1121 | 0.14 | 20.00 | 0.00 | 76 | 0.00 | 20.84 | 0.01 | 44 | 7.48 | 11.12 | 16.8 | 20.0 | > 29.35 | 0.88 | 0.750 | 27.7 | 0.4 |
| 088 | 30 | 2 | 0.765 | oxygen limit | 0.06 | 20760 | 13.76 | 2.72 | 0.01 | 5340 | 3.86 | 15.98 | 0.42 | 361 | 10.82 | 6.16 | 12.7 | 27.7 | 19.54 | 1.04 | 0.765 | 28.0 | 98.0 |
| 066 | 50 | 1 | max | | 0.00 | 135 | 0.06 | 20.28 | 0.00 | 12 | 0.04 | 20.90 | 0.02 | 13 | 8.80 | 9.66 | 30.9 | 48.8 | 25.56 | 1.28 | 0.822 | 99.3 | 99.4 |
| 067 | 50 | 2 | max | | 0.01 | 4900 | 2.72 | 16.96 | 0.00 | 99 | 0.08 | 20.89 | 0.02 | 24 | 8.72 | 9.68 | 30.7 | 46.3 | 25.55 | 1.28 | 0.822 | 99.4 | 99.3 |
| 068 | 50 | 3 | max | | 0.01 | 5760 | 1.32 | 18.28 | 0.00 | 230 | 0.04 | 21.24 | 0.02 | 15 | 8.72 | 9.78 | 30.6 | 46.4 | 25.35 | 1.28 | 0.822 | 99.5 | 99.0 |
| 069 | 50 | 9 | max | | 0.07 | 29800 | 5.32 | 8.32 | 0.01 | 2080 | 0.40 | 21.06 | 0.12 | 121 | 8.84 | 9.32 | 27.2 | 45.9 | 24.09 | 1.29 | 0.823 | 99.5 | 99.6 |
| 059 | 50 | - | max | | 0.00 | 136 | 0.06 | 22.13 | 0.00 | 27 | 0.06 | 23.20 | 0.02 | 22 | 8.80 | 10.78 | 26.3 | 51.4 | 25.61 | 1.28 | 0.822 | 97.8 | 49.8 |

| | | | | | Well | | | | Manifold | | | | Exhaust | | | | Fuel | Elect. | F:A | Manif. | Well | Bypass | Well |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run | Load | Well | Pressure | Notes | CO | HC | $CO_2$ | $O_2$ | CO | HC | $CO_2$ | $O_2$ | CO | HC | $CO_2$ | $O_2$ | cons | load | ratio | press. | press. | throt | throt |
| # | kW | # | bar | | %vol | ppmV | %vol | %vol | %vol | ppmV | %vol | %vol | %vol | ppmV | %vol | %vol | lb/hr | kW | - | bar | bar | % open | % open |
| 071 | 50 | 1 | 0.8 | max vac – detonation | 0.08 | 32010 | 4.22 | 9.86 | 0.01 | 2680 | 0.40 | 21.18 | 0.13 | 141 | 9.18 | 8.90 | 27.6 | 47.5 | 23.08 | 1.25 | 0.800 | 49.6 | 98.4 |
| 072 | 50 | 2 | 0.8 | | 0.06 | 20260 | 13.24 | 3.70 | 0.01 | 2470 | 1.82 | 19.74 | 0.16 | 153 | 10.50 | 7.46 | 28.9 | 47.2 | 21.07 | 1.27 | 0.800 | 47.9 | 98.5 |
| 073 | 50 | 3 | 0.8 | | 0.08 | 31050 | 5.66 | 9.94 | 0.01 | 1787 | 0.46 | 21.32 | 0.09 | 113 | 9.28 | 8.86 | 31.3 | 47.3 | 23.38 | 1.25 | 0.800 | 50.6 | 98.5 |
| 074 | 50 | 9 | 0.8 | | 0.07 | 30610 | 5.20 | 8.24 | 0.01 | 3550 | 0.64 | 20.48 | 0.16 | 196 | 9.34 | 8.36 | 25.7 | 47.4 | 22.24 | 1.24 | 0.800 | 48.4 | 98.4 |
| 065 | 50 | - | 0.8 | | 0.00 | 188 | 0.06 | 20.18 | 0.00 | 17 | 0.06 | 20.80 | 0.02 | 18 | 9.00 | 9.24 | 30.4 | 50.3 | 24.76 | 1.24 | 0.801 | 51.5 | 98.5 |
| 070 | 50 | - | 0.8 | | 0.00 | 750 | 0.12 | 21.10 | 0.00 | 41 | 0.06 | 21.94 | 0.02 | 24 | 9.02 | 9.74 | 32.2 | 47.7 | 24.79 | 1.24 | 0.800 | 51.7 | 98.3 |
| 075 | 50 | 3 | 0.796 | max vac – detonation | 0.09 | 26030 | 7.58 | 3.74 | 0.01 | 4280 | 1.40 | 18.38 | 0.20 | 146 | 10.04 | 6.18 | 24.2 | 46.9 | 19.67 | 1.25 | 0.796 | 43.5 | 98.2 |
| 077 | 50 | 9 | 0.786 | max vac – detonation | 0.07 | 30440 | 4.60 | 8.96 | 0.01 | 5290 | 0.80 | 19.42 | 0.11 | 151 | 9.66 | 7.16 | 24.4 | 25.6 | > 29.35 | 1.10 | 0.828 | 99.4 | 99.3 |
| 076 | 50 | 2 | 0.78 | oxygen limit | 0.06 | 19940 | 12.68 | 4.34 | 0.01 | 3510 | 2.50 | 18.30 | 0.22 | 121 | 11.26 | 5.96 | 25.7 | 46.8 | 19.67 | 1.23 | 0.780 | 38.0 | 98.2 |

## 3.0 CONCLUSIONS

The data indicates that the system is capable of performing the desired function, and of achieving the project goals: hydrocarbon destruction, with reduced fuel consumption and maintenance requirements, using available equipment and fuel, while producing usable electricity. One operational problem identified during the testing will have to be corrected with a system enhancement involving added hardware and software changes. Further development will be required to optimize the equipment for these purposes, to allow the equipment to operate in the absence of an operator, and to enhance the system's operational abilities with added features.

## 4.0 RECOMMENDATIONS

Further development work is recommended to enhance the system's abilities and to correct an operational problem identified during the testing. The system, once completed, could be offered to any military organization worldwide with a need for hydrocarbon destruction.